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The ATLAS Semiconductor Tracker

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1. Physics Goals

The physics goals of ATLAS include searches for the Higgs boson and new phenomena (SUSY...) at high luminosity and b and t physics at low luminosity.

Use a general purpose magnetic spectrometer for the LHC designed to operate at a luminosity of 10^{34} $cm^{-2}s^{-1}$.

Tracking is an important feature of ATLAS and is used for:

momentum measurement
charge determination
electron identification
b tagging
particle spectroscopy
decay length measurement
E/p
calibration

ATLAS Inner Detector tracking concept:

Combine continuous and precision discrete tracking, redundancy

large radii (>~60 cm) dense ~36 layer axial straw tube array (TRT): used for global pattern recognition, momentum measurements, electron ID (TR function)

intermediate radii (30-52 cm) silicon strips (SCT): used for pattern recognition, precision point determination, momentum measurement, triggering

small radii (4-14 cm) Pixels: used for pattern recognition, vertexing, dip angle measurement

2. LHC Environment

The LHC is a proton-proton collider with $\sqrt{s} = 14$ TeV.

Beams collide every 25 ns

At full luminosity: 18 events/crossing

High mass Higgs will require 10 years of running

In regions occupied by silicon strips, radiation levels will exceed 10^{14} particles/cm^2 over the life of the experiment

Fluences for 10 years operation including 50% uncertainty and maintenance scenario

location	radius	z	$\Phi[10^{14}]$	$V_{dep}{}^{t}$	I_{leak}[ma]*
barrel 3	30 cm	75 cm	1.95	390	1.88
barrel 6	52 cm	75 cm	1.16	189	1.12
disk 6 ring 1	26 cm	170 cm	2.09	426	2.02
disk 6 ring 2	32 cm	170 cm	1.68	320	1.63
disk 6 ring 3	44 cm	170 cm	1.32	227	1.27

t: for a 300 μm thick detector
*: from ATLAS module geometry

3. Layout, Design, and Performance

Silicon strip barrel region

- covers $|\eta|<1$, $|z| < 75$ cm
- 4 layers of double sided strip: 30, 37.3, 44.7, 52 cm
- resolution 20 μm per point from 80 μm pitch
- stereo angle 40 mr

Silicon strip forward region

- covers $1<|\eta|<2.5$, $83.5<|z|<278.8$ cm
- 9 disk layers with double sided strips
- same resolution and stereo as barrel

(Pixel system: 2+1 barrels, 3 disk layers/side)

System achieves 7 space points per track (including pixels)

Modular design (~12 cm unit)

2112 barrel modules	34.4 m^2 Si
1976 forward modules	26.7 m^2 Si

total channels = 6,279,168

Basic design features:

Use back to back single sided detectors n+ strips in n bulk

>can operate partially depleted after type inversion
>lower voltages than with p+ strips
>collect electrons - faster
>768 strips, 64 mm sensor - maximize wafer area

Use binary readout electronics: 1 bit system

>minimize off detector processing
>only transmit hit address
>relatively cheap, small area front ends
>achieve resolution specs with 80 µm pitch

Modular design

>single 2 x 64 mm module design in barrel
>3 disk modules
>simplify construction, lower cost
>use high thermal conductivity heat spreaders
>detectors -7^{o} C +/- 2.5^{o} C

Mechanics

>use zero CTE carbon-fibre cylinder support
>cool with binary ice flow

4. Detectors

Detector design is driven by radiation effects

Selected specifications

size	64 mm x 63.6 mm
strip dimensions	768+2, 80 μm pitch
bulk	n, 3 KΩcm<ρ<8 KΩcm
implant	n+
readout strips	aluminum, <20Ω/cm
isolation	individual p frames
coupling	oxide+nitride, >10 pF/cm
passivation	oxide
biasing*	polysilicon, 1.5 MΩ
guard rings	multiple structure
backside	single p implant + guard ring
V operating	300 V after irradiation

Designs optimized by studies of ATLAS prototypes from multiple vendors.

*:On punchthrough biased ATLAS prototypes observe excess noise after irradiation. Appears to be same as effect seen by CDF with FOXFET biased sensors

-->"punchthrough noise"

(P.Azzi et al, NIM A383 (1996), 116-123)

5. Electronics

Parameter	**Specification**
Noise	< 1500 e
Efficiency	99%
Noise occupancy	5×10^{-4}
Bunch cross tag resolution	1 bunch crossing
Occup from wrong crossing	1% of real hit occupancy
Double pulse resolution	50ns for 3.5 fC after 3.5 fÇ
Late charge recovery time	1 µs for 3.5 fC after 80 fC
Max L1 trigger rate	100 KHz
Min L1 trigger spacing	2 bunch crossings
Pipeline length	128 locations
Depth de-random buffer	8 locations
Voltage compliance	+/-10% of nominal
Function range	-10^{o}C to 30^{o}C
Power dissipation	3.8 mW/channel
Radiation dose	2×10^{14} n/cm^2, 10 Mrad

The front end readout is based upon a bipolar preamp-shaper-discriminator followed by a CMOS binary pipeline and readout circuit.

Two implementations:

A) 2 chip design
>CAFE-M bipolar chip fabricated at Maxim
>ABC CMOS pipeline fabricated at Honeywell

B) 1 chip design
>ABCD BiCMOS fabricated in DMILL

Binary architecture based upon extensive prototyping beginning with ZEUS and SDC.

Binary still allows monitoring of fundamental analog performance --> threshold scans

6. Modules

ATLAS module concept determined by:

electrical and thermal behavior
>center tapped barrel design
>use of heat spreader

manufacturability
>small number of designs
>simple, symmetric construction
>bridged barrel hybrid design

material
>BeO hybrids and base plates

Thermal run-away: power dissipated in silicon = $I_{leak} V_{dep}$

I_{leak} depends linearly on fluence and exponentially on temperature.

Heat generated in silicon must be conducted and convected away efficiently.

--> increase effective thermal conductivity of module

Barrel module specifications

mechanical tolerance	back to back: <5 µm (ϕ)
	<25 µm (r)
	<25 µm (z)
	fixation: <50 µm (ϕ)
	<100 µm (z)
strip length	126 mm (2 mm dead area)
strip directions	axial, stereo U/V (40 mr)
number of strips	768/side x 2 = 1536
strip pitch	80 µm
hybrid	size: 74.6 x 28 x 0.38 mm bridged design
detector power	<1 watt@-7^{o}C->70 µw/mm^2
hybrid	4.45 watt
operating temperature	-7^{o} C
uniformity of Si temperature	< 5^{o} C
permanent deformation	< 5 µm after 10 thermal cycles (-20 to 70 C)
hybrid power on/off	< 10 µm
cool down	< 50 µm (30 to -10 C)

7. Mechanics and Cooling

Mechanical support structure

4 concentric barrels:

>two 0.2 mm skins ultra-high modulus CF in cyanate ester resin (CFRP)
>6 mm CFRP honeycomb
>0 CTE in z and ϕ directions
>terminated by 0 CTE CF flange

disks:

>same CF design as barrel
>supported by CF space frame

Alignment

>prototypes measured with ESPI system
>structures surveyed with X-rays at construction
>continuous monitoring with FSI and geodetic grids
>track alignment

Cooling with binary ice

item	**specification**
operating temperature	-14^{o} C input fluid
anti-freeze	99.9% methanol
ice concentration at source	10%
ice concentration at outlet	1%
total tracker heat load	53 kW
total cooling capacity	120 kW
cooling pipe material	aluminum
typical ID	3.5 mm
system configuration	leakless

8. Conclusions

>ATLAS plans a large scale silicon tracking system

>Design motivated by radiation tolerance and reliability

>Conservative approach
- >lower voltages on detectors
- >redundancy
- >simple readout

>Design goals achieved with use of some new approaches
- >thermal heat spreaders
- >binary ice coolant
- >large scale binary system

>Design has been submitted to LHCC as TDR. Goal is to begin construction in 1998.